INTRODUCTORY ACCOUNT OF THE GEOLOGY AND PETROLOGY OF THE LAKE GEORGE DISTRICT.

PART I. GENERAL GEOLOGY.

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(Plate ix; one Text-figure.)

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Scope of Paper.—This paper deals with the General Geology of about 170 square miles of country between Spring Valley and Bungendore, and eastward to Tarago, on the eastern side of Lake George, on the Southern Tableland of New South Wales. A second paper will deal with the Petrology of the area. The work was done partly in 1934 as Deas-Thomson Mineralogy Scholar, a thesis embodying the results being presented as portion of the work for an Honours Degree in that year. During part of 1935 the mapping was continued with the aid of a Deas-Thomson Research Scholarship, and a Science Research Scholarship of the University of Sydney. Owing to his unexpected departure for Fiji, the writer was unable to extend the field examination of some of the more interesting occurrences, but feels that the chances of continuing it in the near future are sufficiently remote to warrant the publication of the results thus far obtained.

The accompanying map (Pl. ix) is based on the parish maps issued by the Department of Lands. To facilitate reference in the text, a grid system has been incorporated. Numbers in brackets refer to specimens, a suite of which is being lodged in the Museum of the Department of Geology at Sydney University.

Previous Records.—Practically the only references to the geology of the neighbourhood are contained in "The Limestone Deposits of N.S.W." (Carne and Jones, 1919), and the "Report on the Federal Territory" (Mahony and Taylor, 1913). Both these deal with the limestone deposits. On the physiographical side, the origin of Lake George has been discussed at some length by Taylor (1907), and several brief references occur in various recent papers by Craft (1928–33).

Acknowledgements.—The writer wishes to record his appreciation of the constant advice, and friendly and encouraging criticism given freely throughout the work by Dr. W. R. Browne. He also desires to acknowledge the practical hospitality of the residents of the district, and in particular that accorded by Mr. and Mrs. W. Overend, of Mount Fairy, and Mr. D. White, of Willeroo Station.

Summary.—Owing to the general absence of fossils and lack of suitable exposures, a definite chronological scheme cannot be given, but the general succession is briefly as follows: The Mount Fairy Series, of shales, phyllites, limestones, tuffs, and minor igneous zones, has, in common with an associated series of amphibolites, been injected by gneissic granite, accompanied by strong folding, and the formation of hybrid or contaminated types. The amphibolite series may possibly be a remnant of an older igneous mass than the shales, which are Silurian. A group of Devonian rocks, including Middle and probable Upper

Devonian, overlies unconformably the Mount Fairy Series and gneissic granite. Following an epi-Devonian period of igneous injection, erosion supervened until the outpouring of Late Tertiary lavas took place.

The Mount Fairy Series.

This name is given to a group of rocks covering an extensive area in the southern and eastern parts of the district. Shales form the chief rock type, but phyllites, sandstones, tuffs, limestones, and minor intrusions also occur, some of which are certainly of Silurian age, and all may well be.

Sedimentary Types.

The dominant rocks are sediments, ranging from fine shales through sandy shales to grits. They are usually brownish-yellow in colour, but in places white, brown, grey, and chocolate shales occur, as in a creek (H.13)* two miles north of Sally Trigonometrical Station. Black slaty and cherty phases do not occur in general, but are fairly well developed in a limited area between about G.10 and E.13. They would seem to be related in some way to the proximity of the main granite mass of the lake. The possibility should not be overlooked that they may belong to an older system, perhaps even Ordovician. Fossils were not found.

So far no definite fossils have been found in the Mount Fairy shales. In the Cookbundoon–Goulburn region numerous graptolitic remains have recently been found (Naylor, 1935) in beds of similar aspect. On Fairy Meadow Creek, between the Public School site and the railway line (J.5), deformed radiolaria occur in a dark cherty band among the shales. A similar rock from Sandhills Creek in southern J.4 contains better preserved types. The bands, a few inches thick in the shale series, contain identifiable *Spumellaria* and *Nasselaria*, in which the centrosphere is visible in some cases. Radiolaria also occur in a slate inclusion in one of the "intrusive tuffs" from Fairy Meadow Creek and probably are abundant in the adjacent rock.

Occasional zones of a more phyllitic character occur in the shales in the main area of the Mount Fairy Series. These could not be shown to bear any constant relation to visible occurrences of granite, but may reflect its presence below the surface. There are also phyllites and mica schists in that part of the area in which the amphibolites and hornblende schists occur in mass, near Red Hill. These occur as bands (intercalated or xenolithic?) in the amphibolite series, and also as xenolithic bands in the granite. On the map they are indicated by the same symbol as the normal Silurian beds, but they are easily recognized, since they occur well away from the main shale series.

Lithologically, these rocks appear to be more highly metamorphosed than the rocks of the Mount Fairy Series which, in addition to shales, includes slates, sericite-chlorite-schists, schistose grits, and the like. The Red Hill phyllitic group has not reached the biotite stage of regional metamorphism, but is still in the chlorite zone, into which the rocks of the Mount Fairy Series fall. Both types have suffered maximum stress, indicated by shearing and fracture, and this to a later time than that of the crystallization of the granite (q.v.). We must then compare them as purely regionally altered types, when the difference in maximum metamorphism amounts at most to a temperature difference wholly within the chlorite zone. This, especially in view of the apparent greater heating effects of the granite near the lake, as shown by the effects on the basic rocks, does not seem sufficient justification in itself for placing the phyllites in an older series. Further discussion of the age really turns upon the interpretation given to the

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* Grid reference to map.

amphibolite series of Red Hill, as being (*a*) bedded volcanics or pyroclastics, of Silurian or, less probably, older age; (*b*) epi-Silurian gabbro, comagmatic with the granite; (*c*) epi-Ordovician gabbro. This is discussed elsewhere. Here it may be said that should (*c*) be correct, the phyllitic series must be pre-Silurian, while in the other cases it could, and probably would, be Silurian.

Pyroclastic Types.

Pyroclastic types are not conspicuous members of the series. A hard dark band (1594) in the shales on Sandhills Creek near Emu Flat Creek was sectioned to see whether radiolaria might not be present. The rock is an extremely fine-grained quartz-tuff; radiolaria are wanting. Probably such tuffs, in narrow bands, are common in the series. About one mile west of the Tarago-Willeroo crossroads, in I.11, a small outcrop of banded rock (1951) occurs. In hand-specimen there is often a contortion of certain bands (only), reminiscent of the contorted varves of the Seaham district, and probably due to the same cause, namely, slumping in the soft sediments. Moreover, slides show that there is unmistakably a cycle of deposition of the type found in varves. Layers of coarser and limonite-rich material pass gradually into finer ones, to end abruptly at the commencement of another coarse band. The bands vary in width from 1 mm. to 0·3 mm. The writer is of the opinion that this rock is the consolidated product of very fine showers of volcanic ash, settling in water. The intervals between showers, though not long, were sufficient to allow of the settling of the finer ash which would remain suspended in the water for some time. An opportunity has since occurred of examining certain rhythmic tuffs in northern Viti Levu, Fiji, and an analogous structure has been observed to be not uncommon in these latter types. Unfortunately the field-relations of the Tarago occurrence are somewhat obscure, but there does not appear to be any reason to doubt that it forms part of the Mount Fairy Series.

Igneous Types.

Associated with the Mount Fairy Shales there is developed, along Merigan Creek and the railway line in eastern J.9 and J.10, a group of hypabyssal and possibly pyroclastic types. There is not much evidence on which to decide whether these are interbedded, intrusive, or both in part. Time did not allow of very detailed mapping, but it appears probable from the field relations that some at least of the felsite is in the form of one or more interformational sills or laccoliths. Owing to alteration, the origin of the rocks is rather obscure, but tuffs, felsites, rhyolites, and even obsidians probably occurred. These will receive more detailed treatment in Part II.

In north-western K.11 chiefly, there is a series of igneous and pyroclastic rocks. They are possibly related to the Devonian occurrences just to the north, but on the other hand their field relationship to the Mount Fairy Series suggests that they form part of this series. The boundary is steeply inclined to the strike of the shales on the southern margin of the group, but there is no evidence suggesting faulting, nor is there any distinction in elevation between them. Possibly the igneous types, which are acid, were very viscous and built up an elevated structure without much lateral extension, to be surrounded by shales. The chief types are quartz and felspar porphyries, tuffs, and a coarse rhyolite-breccia, all now much altered.

"Intrusive Tuffs."

Chiefly on Fairy Meadow Creek and Sandhills Creek there is a development of rather anomalous types. Concordant in general with the shales and slates, and yet showing in places minor signs of transgression, there are rocks which in thin section appear to be of clastic origin. Field-evidence cannot indicate much beyond the transgressive relation, and thin sections are in a measure unsatisfactory on account of a certain amount of silicification and albitization that has occurred. In Fairy Meadow Creek, 14 chains above the junction with Sandhills Creek, K.5, a rock (1716) of this nature occurs, with a number of xenoliths or fragments of slate embedded in it. On the same creek, half a mile above the junction, another (1715) shows a quite definitely transgressive relation to the sediments, but a section shows characters suggestive of a clastic or brecciated origin. Other quite definitely intrusive examples occur on these creeks, tongues of the rock cutting across the shales, and including detached fragments of the wall material.

Rocks exhibiting these peculiar features occur elsewhere in the Silurian of the State. However, a recent summary of their occurrence and characters (Browne, 1929, pp. xv-xvi) renders further notice here unnecessary. Not much fresh light on their origin can be shed by the study of the material from this district.

Limestones.

The limestones of the Mount Fairy Series occur in a belt of isolated outcrops covering several square miles, and exposed chiefly by Sandhills and Fairy Meadow Creeks, to the south-east of Mount Fairy (Mahony and Taylor, 1913; Carne and Jones, 1919, p. 286). Considerable interest attached to the main deposit—the only one considered in detail by these authors—on account of its proximity to the Federal Capital, and a proposal to make use of it for cement for the chief buildings of Canberra.

The limestone occurs in two belts trending meridionally, and with disconnected outcrops. The more eastern of these (K.4) passes through Swampy Creek. The other, narrower but more elongated, runs northwards along Sandhills Creek and then up Fairy Meadow Creek.

The *eastern belt* includes outcrops up to 22 chains in width. The main mass, cleft by Swampy Creek, occurs on the southern side of Sandhills Creek, but another series of outcrops occurs to the north of the latter stream. The general strike of the limestone of this belt is a little west of north, and the dominant dip is high to the west. The limestone is massive and jointed; nevertheless the writer found a number of places where intercalated shales gave reliable dips, though considerable variations occur. One determination near the eastern edge of the main mass, rendered certain by the presence of both shale and fossil bands, gave a strike of 355° and a dip westerly at 65°, and others, somewhat similar, were obtained. Variations may be seen, particularly near the stream at the northern end of the main mass. A determination, strike 115°, dip southerly at 45°, was succeeded just to the south by a strike of 140° and dip of 60° to the south-west, with a regular gradation between. These dips may indicate subsidiary transverse pitching folds in the main flexure of the limestone, or may be taken as contributory evidence of the existence of large-scale faulting.

Faulting in the associated shale series is very common. Some of the faults are normal, while many are thrusts. Often the throw is indeterminate, but in many cases it is of a small order. Faulting also occurs in the limestone, and there is evidence of the existence of at least one major fault. The latter, perhaps influencing the dip anomalies mentioned above, seems, while not clearly defined, to run from west-south-west to east-north-east along and past the northern edge of the main limestone mass. Such faults as this would need to be plotted and taken into account in any exhaustive examination of the limestone masses for economic purposes.

The *western belt* occurs about 30 chains to the west of the eastern. It is much narrower, having only about one-third the maximum width of outcrop of the eastern belt. The outcrops are disconnected, and occur chiefly along Fairy Meadow Creek to Mount Fairy and beyond. A reddish soil which is probably terra rossa occurs in a hollow at the railway line where the surveyed road crosses it in portion 21, Parish of Merigan, a little north of Mount Fairy (J.6). This would be a continuation of the western belt almost directly due north for about a quarter of a mile from the Mount Fairy Public School masses. The length of the belt is thus a few chains short of two miles. Some of the limestone masses on this belt show good stratification, especially those near the school site (J.5–6). One of these shows an excellent exposure of crumpled limestone, indicating fairly considerable depth of cover during folding. The limestone of this belt is given by Carne and Jones as striking N. 10° W., and dipping E. 10° N. at 65°. However, one determination gave a westerly dip of 30° for the limestone on Sandhills Creek near Fairy Meadow Creek.

The boundaries of the limestone outcrops are sometimes quite clear, as on the downstream side of the main mass on Sandhills Creek, but most of those elsewhere, except in creeks, are obscure. Near Mount Fairy and at the lower junction on Sandhills Creek, the gradation by intercalated bands into shales is easily seen; there is no sign of a faulted or eroded junction. The associated sediments are similar to the Silurian beds elsewhere in the district, with some exceptions. There is a greater proportion of coarser beds. Fine and coarse grits and tuffs are associated with the shales west of the limestone belts, and some carbonaceous shales also occur. The rocks actually in contact with the limestone on the west are shales, and between the two belts there are reddish shales. Downstream from the eastern belt, typical shales again occur at the junction, but some chains further down a more siliceous assemblage is found, of quartzites, shales, and phyllites.

Fossils are not numerous in the limestone, and even when they do occur, well preserved and identifiable specimens are rare. They are best developed at the extreme eastern edge of the main mass, on the creek. Forms collected include *Favosites* (several types, massive and dendroid, probably including *F. gothlandicus*); a large *Syringopora* and smaller fossils of the same type; numerous crinoid stems and ossicles. Professor L. A. Cotton has found* a thick band of *Conchidium* (*Pentamerus*) *knightii* in one of the tunnels which were excavated for the purpose of ascertaining the extent of the limestone. The fossil was also found in one of the caves. It links the limestone with other similar ones at Marulan and elsewhere, being considered a restricted form. The limestone was considered by the late Mr. W. S. Dun to be indubitably of Upper Silurian age, and there seems no evidence to the contrary.

The question, however, arises as to the age of the western belt, since it is the eastern one which contains the above fossils. Fossil traces were found in the western belt, but not well enough preserved for identification. In favour of the limestones being of similar general age, we have the very similar strikes and degree of dolomitization of the two belts. The apparent gradation in each case into the shales between indicates continuous sedimentation. Moreover, the occurrence of a similar sequence of two belts, one thick, and the other narrow.

* Personal communication.

or a succession of thin beds, at Bungonia, Marulan, and Windellama, is significant. These are all Upper Silurian, as is the main belt on Sandhills Creek, and their existence is not inconsistent with the suggestion that the western belt on Sandhills Creek is likewise of Upper Silurian age.

A series of large caves exists in the main limestone mass, but they were not explored. As there cannot be caves below stream level, any of importance are likely to be confined to the eastern belt. The weathering of the limestone is of the orthodox type. The characteristic terra rossa is present in many places, though largely washed off by sheet erosion.

The suitability of the limestone for cement making has been considered by the Federal Government, more especially in connexion with the building of the Federal City. Two reports issued (Mahony and Taylor, 1913; Parl. Papers, 1916) contain information on this subject. Analyses, plans, cement tests, and tonnage estimates are given. Tunnels more than 200 feet in length have been driven into the main mass, which has been contour surveyed. Quite recently the dolomitic portion of the deposit has been opened up. The rock is being used by Hoskins' Iron and Steel Works at Port Kembla, presumably for lining furnaces.

Conditions of Deposition.

The dominance of shales in the series indicates the general prevalence of quiet sedimentation in water free from violent or persistent currents. Some reliable conclusions may be drawn from consideration of lithological features.

The very widespread occurrence of the Mount Fairy shales requires for its explanation the postulation of a sea of considerable area. That this was marine, in part at least, is shown by the association of radiolaria and of limestone beds. However, study of the rocks cannot fail to convince one of the applicability of Barrell's generalization that such seas in past geological time may have been wide, but certainly were not deep (Barrell, 1917). The intercalation, at intervals, of beds of fine sandstone, and even occasional grits, points either to continued shallow-water deposition or to an inconveniently rapid oscillation of the strand line. The limestones also contribute to this conclusion, inasmuch as corals flourish at a depth not greater than about 120 feet. A somewhat more subtle significance lies in the frequent occurrence in the shales and fine sandstone of miniature current-bedding. Good examples occur on a creek (southern part of F.4) tributary to Dry Creek, and also on Sandhills Creek at a number of places in J.3 and J.4. The deposition within the limit of occasional current action is obvious. But whereas currents may stir sediments at quite considerable depth, these must have been stirred at very small depth. For the thinness of the current-bedded bands (half an inch or less) requires very feeble currents, acting not far from the surface. At a greater depth stronger currents would have to be present, and these would have scoured out channels in the fine sediment, and could not have failed to stir feet of the muds, rather than a centimetre.

Signs of cycles in the sedimentation, and also in the contemporaneous vulcanicity, are common. On a large scale, we have the alternation of sandstones and shales. At Rocky Point, also, rhythmic banding of a large order of magnitude is very well shown in numerous exposures. There is some doubt about the correlation of the isolated Rocky Point mass with the Mount Fairy Series, on account of this banding, and also because of the indurated and rather more arenaceous type of sediment. Alternation of limestone and shale bands in the creek near Mount Fairy (J.5–6) is very regular. The distinct rhythm displayed by banding in the varve-like tuffs from I.11 has been commented upon already.

In a number of places the periodic banding in the shales or sandstones is very pronounced, and invites investigation with a view to possible determination of the nature or period of the cycle, as has been done by Gilbert and others. On Dry Creek in F.3 is such an exposure, and another is in a measurable position in the creek bed at Mount Fairy near the railway line. Alternations are excellently exposed in the slates on Taylor's Creek where it turns from north to west (G.9). The average thickness of the bands is about one-third of an inch. On Sandhills Creek, J.4, the average thickness of the bands, which are very well shown, is half an inch and three inches respectively. At the same place there is also a rhythm, of magnitude decreasing upwards from 18 inches to a fraction of an inch, of bands with strongly marked current-bedding, and laminated white shale beds between. The thicker current-bedded bands are not simple, but multiple, again illustrating the feebleness of the current action, even though prolonged more than usual. The picture conveyed to the imagination is one of unsettled conditions of deposition, periodical in incidence, but of waning intensity.

Palaeogeography and Climatology.

The palaeogeography of the Mount Fairy Series is somewhat obscure. At present it is not easy to state the bounds of the area over which rocks of this age outcrop. The Upper Silurian sea apparently was not deep, but was undoubtedly extensive. The limestones may point to the possible existence of a shore line to the east of Mount Fairy, though there is no reason to doubt that, in such a palaeozoic shallow-water sea, coral reefs could flourish far from land. The presence of volcanic rocks and, to a less extent, of pyroclastics, in the Tarago area suggests active volcanoes near the land, or perhaps on it. But such outpourings could quite easily have originated in submarine eruptions, a view which is indeed favoured by the occurrence of extensive deuteric alteration in them and by the abundant occurrence of these types of rock in the Silurian of the Cooma-Canberra region.

Climatic conditions in Upper Silurian time represented by the Mount Fairy Series were evidently moderate. The limestones indicate warm seas, for a time at least. It may be suggested that the clouds of volcanic ash emitted from time to time may have exercised a pronounced temporary cooling, as has often been urged by advocates of certain climatic theories, and has been indicated by modern instrumental observations by Abbott and others.

Structure of Mount Fairy Series.

It seems difficult to come to any other conclusion than that the Mount Fairy Series has been closely folded into a series of almost isoclinal overfolds, with axial planes dipping west. On seeing, throughout the district, numerous instances of this close folding—folds with a wave length of a few yards and even less—it does not seem reasonable to assume, on consideration of the uniform nature of the beds, that the close folding is but local, especially in view of the total absence of any evidence of the existence of more open folding. Excellent illustrations of the isoclinal folding may be seen in the following exposures: Emu Flat Creek, in north-eastern I.3, where the validity of the subsidiary corrugation test for anticlines and synclines finds an excellent demonstration; on Sandhills Creek numerous sections illustrate the close folding, as in south-western J.4 and north-western J.3; at the Mount Fairy Railway bridge, and in the cutting about 400 yards south of it (both in J.5), where the close folding may be seen; the big bend in Taylor's Creek in G.9—a storehouse of illustrations of various features of the Mount Fairy Series—shows the close folding to advantage, and also its discrepant attitude to the cleavage.

The almost invariable dip to the west, both of bedding and of schistosity, is strong evidence in favour of isoclinal folding, especially in view of the very variable amount of dip, precluding one large simple fold with corrugations. Exceptions with regard to both bedding and schistosity dip do occur, but are rare. An easterly dip of beds is to be seen near the bend of the road in K.12, and also on the Bungendore road just south of the area shown in the map. These anomalies are easily explained as the accidental exposure of the short east-dipping limbs, or as a local, rather more open, folding.

If close folding be such an essential feature as is thought, there must have been considerable crustal shortening due to pressure (from the west, see Hobbs, 1914). It is likely that the isoclinal folds dipping west form part of the one limb of a huge synclinorium (or anticlinorium); following the mechanical principles involved, the folds probably represent part of the eastern limb of a synclinorium, and the beds to the west of Lake George, with a large proportion of easterly dips,* could represent the western limb. Another result of the isoclinal folding is that it is quite impossible to form any idea, with data now available, of the thickness of the Mount Fairy Series.

Exposures showing the close folding of the shales also indicate a considerable pitch for the folds. A dominant direction of pitch cannot be given from the data known. One effect of the pitch is to modify to some small extent the observed values of strike and dip. The general strike is north or a little west of north. But considerable variations, partly along lines of shear, occur, up to 45° and even 80°. Darwin ("Geological Observations", p. 251) mentions the dominant northerly strike. No definite relation could be seen between the local strike of the shales and the boundaries of the granite, though the latter is, in general, concordant. Occasional belts of silicification occur in the shales, and run parallel to the strike. This is probably due to the penetration by magma and magmatic waters along these lines (see under "Gneissic Granite", below).

Geological Age.

Evidence of the age of the extensive Mount Fairy Series is as yet indirect and inconclusive. The shale series has not so far yielded fossil remains. Reasons have been given already for placing the Mount Fairy Limestones in the Upper Silurian. The eastern belt is interbedded with sediments on the eastern side; its western boundary is indefinite. The western belt is interbedded, as may be seen near Mount Fairy. There is no evidence that these limestones have faulted junctions with the shales. It seems fairly certain from this point of view that, so far as stratigraphical continuity is maintained, the Mount Fairy Series is of Upper Silurian age. An unconformity is later described between the Mount Fairy Series and a Middle Devonian Series, indicating the pre-Devonian age for the former as a probability. The granites which inject the Mount Fairy Series form what Billings has termed a synchronous batholith, and reasons are later

* Personal observations by writer.

given for regarding them as probably of epi-Silurian age; in this case there is a strong presumption that the sediments are of Upper Silurian age, in part at least.

Conclusions based on lithology will always remain open to criticism, but due consideration of it must often be of service. In the present case, there can be no doubt that the lithological criteria are sufficient to place the Mount Fairy Series as pre-Devonian, as shown by comparison with nearby Devonian types—the coarse Middle and Upper Devonian of the Tarago–Goulburn district, and the Lower Devonian volcanics of the Murrumbidgee area. The great dissimilarity of the shales to Devonian rocks of this part of the State is paralleled only by the closeness with which they resemble the characteristic type of the Upper Ordovician and Silurian of the surrounding region.

From a consideration of the foregoing factors, the writer has concluded that the Mount Fairy Series is certainly pre-Devonian, and probably Upper Silurian in age, though there is a possibility that it is, in part, of Lower Silurian age. Lower Silurian rocks have recently been described from the neighbourhood by Naylor (1935).

Devonian.

Rocks of Devonian age occur on Woolowolar Ridge, and its northerly extension across the road towards Tarago. Briefly, the succession consists of limestones, at and near the base, followed by a thick series of red beds, and then by shales, sandstones, felsites, and porphyries in alternating fashion. The general structure appears to be a syncline pitching to the south, probably with one or more cross fractures.

Limestones.

The chief outcrops were mapped as well as practicable. Some of them are mentioned by Carne and Jones (1919). Outcrops occur to the north and south of the road-cutting in K–L.12; this mass is about 60 yards by 150 yards, elongated east and west. Two rather irregularly exposed outcrops occur on the hill about half a mile north of this one, and a small one some chains south of the creek. Further exposures were found in the large tributary creek in northern K.12, interbedded with shales and other sediments.

Dips are easily obtained in the main mass, both in the creek and the road-cutting. The strike is N.20° W., and the dip westerly at 20–25 degrees and more. Bedding is well developed, and accentuated by intercalated shale bands. Dips in the next northerly outcrops are not obvious, but some of the limestone in the more easterly of the two outcrops is bedded, in the bank of the creek. The strike obtained, N. 5° W., with westerly dip, accords with the observation of Carne and Jones. Along the tributary creek the limestone bands and calcareous shales were found to strike from 90° to 150°, dips varying from north at 60° to south-west at 25–51°. These latter beds are apparently part of a series of sediments, fairly closely folded, and of steep pitch.

Fossils were sparingly present in the larger deposits. The chief forms found were *Favosites* sp. and *Receptaculites ? australis*; these were obtained from the smaller of the two outcrops in north-eastern K.12. The presence of *Receptaculites* indicates that the limestone is probably of Middle Devonian age, since in New South Wales this fossil is characteristic of the Middle Devonian, though it is also found sparingly in the Upper Silurian. Confirmatory evidence of the age of the Tarago limestones is to be found in their probable continuation northwards at Lake Bathurst, where they are quite fossiliferous in places, and brachiopods of Devonian aspect occur.

Red Beds.

The Red Bed Stage comprises a thick series of boulder beds and tuffs outcropping as a horseshoe-shaped exposure to the south of Tarago. The deposit varies from a very coarse boulder rock, with individuals up to three feet in greatest diameter, to a fine-grained rock with grainsize less than one millimetre. The boulders are well rounded, and are chiefly of much altered aphanitic acid rocks. A detailed search was made for scratched or faceted pebbles such as would suggest ice or fluvio-glacial action, but none was found. The large boulders are well seen in the section along Merigan Creek, K.11. Splendid sections are also to be seen in some of the gorges on the western side of Woolowolar Ridge. One of these is deeply incised into the mass, K.10, and the gorge walls give an impressive idea of the magnitude of the deposit, which is possibly one of the finest conglomerates to be seen in the State.

There is not only no positive evidence that the beds are fluvio-glacial, but there is definite circumstantial evidence against it. The underlying limestone has its connotations, though of course there may have been a time-break between it and the conglomerates. Moreover, there is no evidence of Devonian refrigeration in the State—or continent—as far as the writer is aware. The red colour of the beds has also certain climatic implications, as will be seen below, and these do not include excessive cold. The finer material is at least dominantly pyroclastic; the boulders are rounded, occur in more or less separate beds, and may or may not be of pyroclastic origin. The most appropriate name for the rock is probably tuffaceous conglomerate.

The brilliant red coloration of the Red Bed Stage is a striking characteristic. Red beds are often referred to as indicating in some vague way that the rocks were formed under arid conditions—presumably on the precedent of the red sands at present forming by exsudation in some deserts. Dorsey (1926) has shown that the redness is not due to a relatively high iron content, nor yet only to the presence of ferric iron-oxide—the form in which it is usually present in sediments. The question, he points out, really turns upon the state of hydration in which it is present, which may vary from $2Fe_2O_3.3H_2O$ to Fe_2O_3. The latter (haematite) is red, while each of the four hydrates has another colour. As pointed out also by Tomlinson (1916), the conditions necessary to produce the dehydrated ferric oxide need not coincide with those undergone by the rock at any stage. For this oxide, once formed, is stable, and may be deposited as sediment under totally different conditions. The chief factors in the production of the anhydrous oxide are time (it being slowly spontaneous) and heat (by which it is accelerated). Dorsey shows that optimum conditions are found "not in deserts—which are practically never red—nor in semi-arid climates, but in warm, moist, heavily forested regions similar to the tropical and sub-tropical areas of the earth today".

Dorsey states that, once formed, the red colour is permanent unless the oxide be chemically reduced. From this and field evidence he deduces that red beds are best formed under continental or freshwater conditions, the reducing effect in marine deposits being inhibitive. This makes the question of the occurrence of limestone with the Red Beds at Tarago an interesting one. Tomlinson remarks that where limestones do occur with red beds they are nearly, or quite, barren of fossils. This is also true of the only limestone at Tarago actually seen to underlie the Red Beds, but the few fossils which do occur in it are sufficient to indicate its marine origin. There may have been a time break between the limestone and red beds, and deposition of the latter under continental conditions, after uplift. Again, possibly the violent current carrying the boulders, or the rapid showering of ash and boulders—depending on the precise origin—was sufficient to cause the local suspension of true marine reducing conditions.

Mapping of the Red Bed Stage south of the road shows the outcrop to have a horseshoe shape, with the apex to the north, on the road. The western limb thins out and disappears, and the eastern one does likewise at about the same latitude. Dips could not be obtained on the eastern limb, owing to the weathered outcrops. At the apex, the beds are crushed and shattered, and dips meaningless. In the western limb, good exposures enable dips to be read from bands of finer or coarser material. The dips thus obtained are of doubtful general value. Some were to the east, but others were to the west. Evidence of contortion, crushing, and close folding in cuttings shows that the dips would be expected to vary in this way. More reliance should be placed on the obvious connotations of the relation of outcrop to contour, which make it unreasonable to consider the structure as other than a syncline pitching to the south. This pitch makes it seem likely that the Red Bed Stage continues as a sub-surface mass some distance further south than shown on the map. The effect would be that of the spreading out in plan of the superincumbent quartzites and other rocks. Possibly there has been transverse faulting of the structure about along the line of the Tarago road-cutting, with probable uplift of the structure to the north. In the section, the Red Beds are indicated as being folded in a syncline, with minor folding or corrugation of the whole. Owing to the absence of what may be taken as a general dip, and to the presence of minor folding and possibly strike-faulting, it is difficult to assess the probable thickness of the Red Bed Stage. The greatest normal width of outcrop, on the north-western side, is 24 chains. From this the maximum thickness would be, with a dip of 30°, about 800 feet, and with a dip of 70°, 1500 feet.

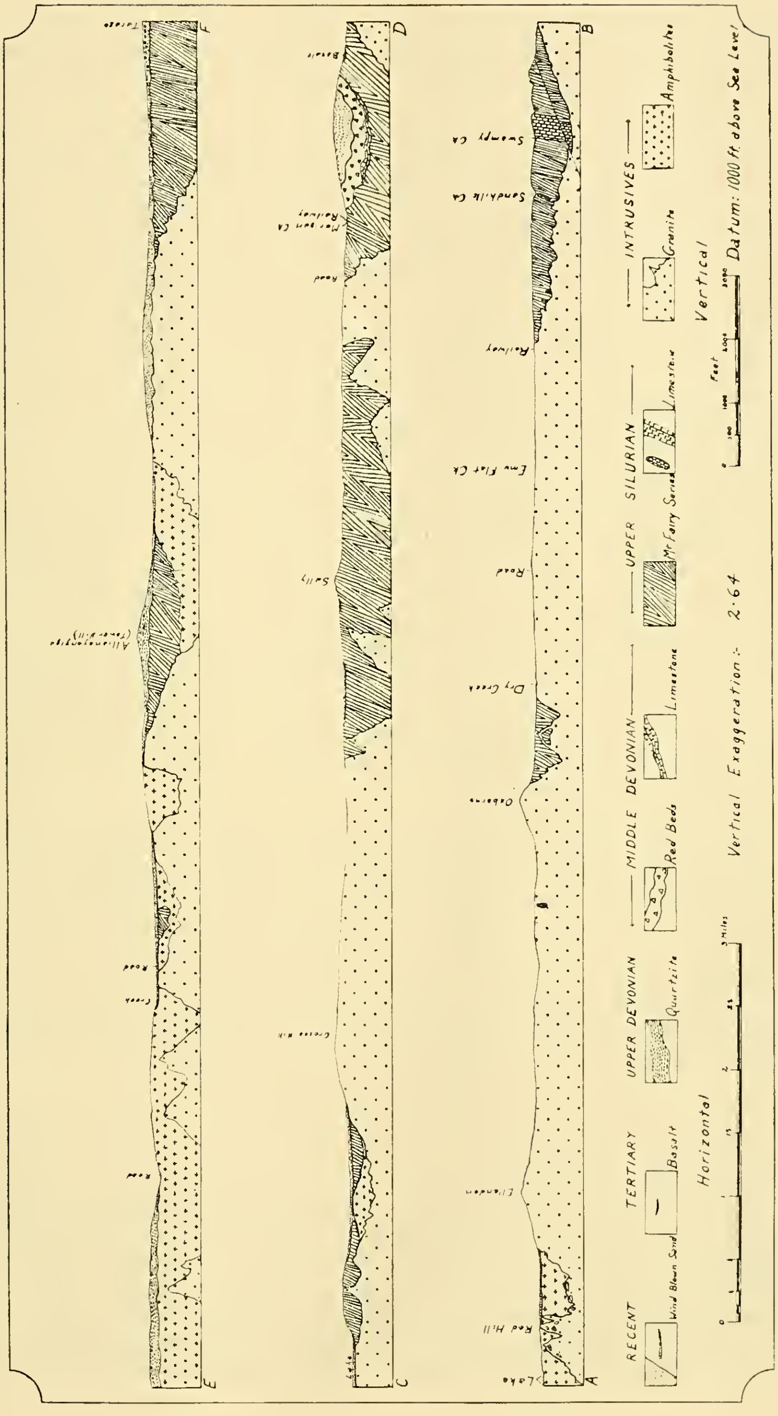
The Red Bed Stage must be either Middle or Upper Devonian in age. The apparent structural continuity with the limestone supports a Middle Devonian age, since there are reasons for believing an unconformity to separate the Middle and Upper Devonian in this region. Similar rocks, though not with the abundance of large boulders, occur associated with the limestone of Middle Devonian age at Lake Bathurst; they also occur underlying the white quartzites of Memorial Hill, Goulburn.

Felsites, Quartzites, etc.

Overlying the Red Bed Stage in the synclinal trough there occurs a series of felsites and porphyries, with quartzites and slates. The slates are both black and grey. The quartzites weather into boulders which much resemble those weathered out from the red beds after the haematite coating has been removed, and have thus rendered the mapping of the latter difficult in places. The felsites and porphyries appear to be flows interbedded with the sediments. With regard to structure, these rocks present difficulties which are not easily overcome. Dips are obtainable only on the western slope of the ridge, and have a dominant westerly nature. If the beds be truly conformable with the Red Beds, they should be expected to partake of the synclinal structure. Either the synclinal structure is very asymmetrical, or the two series are unconformable. The felsite-quartzite

Text-figure 1.

Sections drawn along the lines shown in the map (Plate ix). The thickness of the wind-blown sand is probably considerably exaggerated. The folding of the Silurian and Devonian systems, and the sub-surface boundaries, are diagrammatic only, as is also the faulting in the limestone of section A-B. In section C-D, the Upper Devonian is shown as resting conformably upon the Middle Devonian Red Beds and Limestone, though possibly there may here be an unconformity, as discussed in the text.


A
B
C
D
E
F
Lake
Red Hill
Ellendon
Osborne
Dry Creek
Road
Emu Flat Ck
Railway
Sandhills Ck
Swampy Ck
Basalt
Morgan Ck
Railway
Sally
RECENT
Wind Blown Sand
TERTIARY
Basalt
UPPER DEVONIAN
Quartzite
MIDDLE DEVONIAN
Red Beds
Limestone
UPPER SILURIAN
Mt Fairy Series
Limestone
INTRUSIVES
Granite
Amphibolites
Horizontal
Vertical
Feet
Vertical Exaggeration :- 2·64
Datum: 1000 ft above Sea Level

group shows close resemblances to Upper Devonian rocks in the surrounding region which have been studied by the writer. The suggestion of an unconformable relation of Upper to Middle Devonian is supported by the recent work of Dr. Ida A. Brown (1932).

To the north of the Tarago road-cutting, olive-coloured shales, quartzites, and calcareous shales occur interbedded with the limestones (see above). It is not clear whether these rocks are of Middle or Upper Devonian age. The limestones are not fossiliferous here, but it is to be expected that they are related to the nearby *Receptaculites* beds. Besides these beds associated with the limestone bands, there is also an extensive series of felsites and quartzites to the north and west of Tarago. In the railway cutting north of Tarago, the folding of the beds is well seen. The general strike is 135°, and the overfolds pitch to the north-west, and have axial planes dipping to the south-west; the general dip of the beds is north-east at about 60° in the central part of the cutting. In the northern part of the cutting there is a dominant south-westerly dip; here an interbedded felsite band is followed by shales, and then quartzites. Further west, in the neighbourhood of Tarago Trigonometrical Station, felsites, tuffs, and quartzites occur.

To the west of Tarago, a prominent range of mountains trends west-north-west through Tower Hill, and turns northwards to pass to the east of Spring Valley; another branch follows around the northern shores of Lake George. This range consists practically entirely of massive white quartzites, in places standing up in conspicuous walls. There is little sign of structure in these quartzites, and very few dip or strike determinations could be made. The few which were made gave no predominant trend for the rock. In the north-western corner of the map there is a greater tendency for brown and yellow shales to accompany the quartzite.

These quartzites are regarded as of Upper Devonian age by lithological analogy with other rocks in the neighbourhood, such as the Goulburn quartzites. Their strong overlapping of the Mount Fairy Series and the gneissic granite, well seen on the map, also supports this view.

Relation of Devonian to Silurian.

Unfortunately, exposures showing this relation directly are scarce. No clear indication may be seen in the Tarago district, although consideration of the Devonian synclinal structure—for the Middle Devonian at least, which may itself be unconformable beneath the Upper Devonian—and the isoclinal folding of the Silurian, indicates unconformability. It is probable that the Middle Devonian lies unconformably upon the Silurian. The case for the Upper Devonian, if this be granted, must follow immediately. Independent evidence is to be found in the overlapping mentioned above, and the irregular lower surface of the quartzites to be found along the north-eastern foreshores of Lake George.

Tertiary to Recent.

The deposits of this age are of minor importance. They comprise basalt, lateritic beds, and various soils.

Basalt.—A patch of basalt occurs 13½ chains to the west of the Tarago–Boro Road, L.11. It forms a capping to gravels with predominant quartz and quartzite pebbles. In turn, a layer of ironstone caps the basalt. The latter is about 20 feet in thickness, and occurs on a flank of the wide valley which runs northwards to join Mulwaree Creek to the south of Tarago. The mass is seen to separate two minor creeks flowing into this meridional valley; it seems likely that the flow filled the course of a lateral valley to the main stream, covering the gravels therein, and causing the diversion of the drainage. There are no field criteria by which a definite age may be assigned to the basalt, other than that it is later than the underlying gravels. A similar degree of uncertainty holds with regard to these. Microscopical evidence indicates the similarity of the rock to the group of "Plateau Basalts" of this State (Browne, 1933), which are probably the most common type of Tertiary extrusive on the Central and Southern Tablelands.

Lateritic types.—A deposit of lateritic rock, a few chains square, in L.11, is probably to be related to the former presence of basalt; similar basalt occurs nearby. In H.13 also, and surrounding areas, patches of ferruginous material occur associated with gravels and white quartzite. Here again, these types are no doubt due to the action of a former covering of basalt, silicifying and impregnating with iron the underlying rocks.

The occurrence of a thin layer of ferruginous material on the surface of the bedrock of many streams is of interest; this coating, which may have a pisolitic structure, is often overlain by many feet of alluvium. There is evidence that the deposition was not confined to any period of the Tertiary, but that it is even going on at present. Favour is not found with the idea that it is due to leaching of the underlying rocks. The simplest explanation of the occurrence, which resembles that of a viscous fluid flowing down the bare rock channel, is that the material has come in solution from above. Surface water sinking through the alluvium dissolves out some of the iron and carries it to the bedrock, down along which it percolates as a sub-surface stream, depositing the iron again among the gravels as it goes.

Gneissic Granite.

Under this heading are included not only the typical gneissic granite found in the vicinity of the Lake, but also those variants of it, such as felsites and porphyries, which occur as well.

General Occurrence.

As seen on the map, the gneissic granite outcrops chiefly as a large, more or less elongated body in the central part of the area. Omitting the alluvium and Devonian quartzites, the western boundary of the gneissic granite on the map may be taken as the eastern boundary of Lake George. On the eastern side the granite is bounded by the Mount Fairy Series. In the latter series many exposures of the granite are uncovered, as to the south-west of Tarago. The general elongation of the part of the bathylith exposed is a little west of north.

Nature of the Bathylith.

The gneissic character of the rock is more pronounced on the western side than to the east. On the eastern side there is also a greater tendency for the occurrence of masses of porphyry and felsite associated with the granite. The general elongation of the granite-mass corresponds with the direction of average strike of the Mount Fairy Series. Apophyses and tongues from the main mass also have this trend. The foliation of the gneiss is likewise predominantly parallel to this general direction, with minor deviations. On the other hand the relation "the banding or foliation (of the gneiss) being parallel to the boundary of the intrusion" (Browne, 1931, p. 115) implied or expressed by many workers, is not at once apparent here. But the bathylith has only just begun to be uncovered, as is shown elsewhere, and variations in the topography produce marked changes in the boundaries. The foliation actually is approximately parallel to the solid (as opposed to surface) boundaries. There is reason for believing that ridges such as Governor's Hill, D.7, and Osborne Ridge, F.4, represent the original shape of the roof of the bathylith, and the walls are thus, here, at least, steep.

Although the bathylith in general conforms to the average strike of the shales, I have stated above ("Mount Fairy Series") that it is by no means usual for the strike and dip of the shales to accord with the boundary of the nearby igneous rock. Indeed, as may be seen from the map, especially in H.8, the strike of the shales is frequently distinctly oblique to the contact. It was found that the tendency for this to occur was greatest near the more felsitic phases of the intrusive mass, and especially well marked where apophyses of felsite or porphyry have insinuated themselves into the sediments. These facts were interpreted as indicating a decrease in the power of penetration of the magma as the emplacement of the bathylith progressed. The magma, forced up along an axis of structural weakness, was at first able to soften and absorb without deformation the folded shales, but later on, as the injection neared completion, the magma was unable to carry this out so effectively. Instead, it resorted to a forcible thrusting aside of the sediments, exhibiting a determination to displace, if not to absorb, them. It is possible that in these later phases we have an example of the transition from bathyliths of the synchronous type to those of subsequent type (see below). Since the preparation of the map and manuscript for this paper, the writer has noted with interest the description by Mayo (Mayo, 1935) of similar thrusting effects in the Sierra Nevada, California.

The occurrence of felsitic phases of the granite is interesting, as it does not seem to be usual in bathyliths of this type. As stated above, they are more prominent to the east, but it was not practicable to map them separately from the granite. No doubt they were injected somewhat later than the more coarsely crystalline granite, but before the cessation of regional stresses. In support of this may be quoted the occurrence of the felsites as dykes cutting the granite. An example is an east to west dyke, five to six feet across, of banded felsite (1588) with marked flow structure, seen especially well on weathered surfaces, in I.5. Again, on Dry Creek, felsite veins and plugs cut the laminated granite. The aplites and pegmatites, when they occur, are also distinctly later than the granite. Pegmatite was not seen to cut the country rock at any place.

Using the criteria recently enunciated (Browne, 1931) for distinguishing synchronous from subsequent bathyliths, the present example in the main may be placed in the former category, except for the possible transition noted above. With the proviso that but little pegmatite is present, the occurrence accords with each of the criteria given for this group, and not with any of those for the subsequent group.

The main folding of the Mount Fairy Series is inexplicable other than as having antedated the intrusion of the magma. On the other hand a large body of facts could be assembled to show the continuance of stress until after the completion of the crystallization of the rock. The petrographical and field evidence both point to this.

Xenoliths.

Xenoliths are common in the granite, and they are of several different kinds.

Blocks of slate rifted off from the roof have become engulfed in the magma. For the most part these do not differ petrographically from the country rock. Assimilation is not seen in progress. Xenoliths found near the margins are found to be undeorientated, and it would appear that the remarks of various writers on the oriented inclusions of related bathyliths apply to the more or less marginal ones. Slate xenoliths well away from the margins of the mass were found in general to show considerable rotation from the usual limits of strike of the massive slates.

A dark porphyritic rock occurs as xenoliths in several places, as on Dry Creek in G.4. The white phenocrysts in the rock stand out on weathered surfaces; they are of heavily sericitized plagioclase. Sulphides of two colours occur, the more brassy being better crystallized. In thin section the rocks show alteration of the felspar, and change of augite to hornblende.

Irregularly distributed through the granite, over most of the area, dark xenoliths occur which vary from uralitized dolerites to epidiorites and even schistose types. Most of them contain a good deal of sulphide. Some of those near the main amphibolite mass of Lake George show resemblances to it. Others, while they must have been dolerites, are of obscure origin. The distribution, and examination of the outcrops of the rocks leave little doubt as to their occurrence as xenoliths.

Spring Valley Granite.

In the vicinity of Spring Valley, in the extreme northern section of the map, is shown the southern part of a granite-mass extending to the north. It is bounded for the most part by amphibolites of the Red Hill type. Owing to interruption of the work, this granite was not followed far to the north. While it may be a further extension of the gneissic granite just described, there is also a possibility that it may be younger. In handspecimen the granite is of a massive type in comparison with the Lake George material. There is a large granite bathylith extending from the Goulburn-Gunning road southwards through Wologorong and Tarago Lagoon, and it is possible that the Spring Valley occurrence may be a still further southerly extension of this. In a thesis presented at Sydney University in March, 1935, this was regarded as being of Upper Devonian (Kanimbla) age.

The Amphibolite Series.

Under this head are included rocks of several modes of field occurrence, and also rocks of greatly differing constitution. To the north and east of Lake George these basic types occur as a meridional belt extending from Spring Valley to Bungendore. Further exposures occur to the east of this, along the Willeroo–Tarago road. The rocks are for the most part intimately associated with the gneissic granite, and in part form hybrid types with it. The numerous dark crystalline xenoliths to be found almost anywhere in the granite-gneiss are in many cases undoubtedly derived from the amphibolite masses.

The larger outcrop near the north-western corner of D.4 is typical of the hornblende-schist group. The rocks have the appearance of a bedded group (see strike and dip direction on map). Hornblende-schists, some of which contain clouded felspars, epidote, and porphyroblastic felspars, form the chief type, but hybrid zones and zones of more massive amphibolite also occur. These will be described in more detail in Part II.

The more massive and less obviously banded part of the basic series is best illustrated by reference to specimens from the area about Red Hill, C.6. Some of the types here are very similar to those occurring in D.4 mentioned above, but others of them are not. Hybridization has been fairly extensive, and all gradations into gneissic granite are to be found in the field. Tongues of progressively lighter or darker coloured material weave their way, with indefinite margins, among the slightly less acid or basic host.

The area of amphibolites shown on the north-eastern foreshores of Lake George, just west of Kenny's Point, contains types which are again in intimate relation to the granite-gneiss, and which differ considerably from the rocks occurring at Red Hill. Augen structure is common in the amphibolites. Cores of augite are sometimes seen within the amphiboles. There is here also much evidence in the field of absorption of blocks of the more basic rock in the later granitic types of magma.

To the north and east of the Kenny's Point group, further large masses of the amphibolite series are met with. These are not so variable as those just discussed, however, and are dominantly fine-grained hornblende-schists.

It is rather difficult to decide what was the origin of the members of the amphibolite series. On the one hand, we have the evidence of field structure and occurrence, and that of the microscopic examination of slides, to indicate that the rocks of D.4 especially have their origin in bedded igneous rocks or basic tuffs. On the other hand, most of the occurrences other than those in D.4 appear to have commenced with massive basic igneous rock, suggested by the Red Hill types, for example. The microscopical evidence indicates also that there was a first period of regional metamorphism, converting the rocks into various kinds of hornblende-schists. The chief question is to reconcile these. It may be that the greater part of the mass was originally an igneous intrusion of gabbroic nature, and that the more sheet-like southern portion was due to the development of sills or dactylitic intrusions into the country rock at the extremity.

The age of the amphibolite series cannot be definitely stated. It may be considered as an epi-Silurian intrusion probably comagmatic with, and heralding the injection of the gneissic granite. According to this view, the phyllitic group of the Mount Fairy Series near Red Hill would be explained as occasioned by the additional heat supplied by the gabbro during the regional metamorphism which must have closely followed the latter, but preceded the granite; the latter follows from the consideration that the strain effects of the granite-gneiss are not sufficiently strong to suggest that the same stresses could have formed the hornblende-schists. However, the facts pointing to the amphibolites being older than the Mount Fairy Stage form a more convincing assemblage. In the first place the pronounced regional metamorphism which they have undergone strongly suggests their having been involved in an earlier strong orogeny—of the type believed to have closed the Upper Ordovician in this part of the State. The phyllites and mica-schists of Red Hill may not really belong to the Mount Fairy Series at all, but to an earlier group. An epi-Ordovician age for these basic rocks would also supply an analogy to the rather similar basic rocks found further south in the Bungendore–Cooma region. The presence of hybrid gradations between the amphibolites and granite-gneiss certainly would seem to favour their having been injected in fairly quick succession, leaving little time for the earlier rock to cool off. But the fact remains, that the basic rock must have completely solidified and been regionally metamorphosed before the intrusion of the granite, seeming to make residual heat of little importance. Moreover, the influence of the heat content of a rock mass on its absorption by a later mass is at present an unknown quantity. Earlier ideas required the supply of a considerable amount of heat to effect absorption. Bowen has shown this to be erroneous, on theoretical grounds, and the recent considerable amount of study given to cases of extensive assimilation and contamination seems to minimize its importance.

Summing up, it appears that the most likely age of the original basic intrusions forming the amphibolite masses of the Lake George District is epi-Ordovician.

Minor Igneous Intrusives.

Basic Rocks of Lower Crisps Creek.—Outcropping in Crisps Creek, K.12, twelve to twenty chains above the road bridge is a group of diabasic rocks, which appear to cut the sedimentary series as dykes trending 295°. They can be followed a couple of chains up the hill on the north bank in places. On the south they are obscured by rapid weathering; there is an outcrop in a small road-cutting, but none shows at the surface. Some of the rock includes fragments of the surrounding slate. The intrusion (1858) is about five feet wide, and is typical.

Thin sections show the rocks to belong perhaps to the quartz-dolerite group. Carbonation and albitization have taken place; the augite is in many cases represented by quartz, chlorite, and carbonate. The dykes appear perhaps to have a relation to numerous quartz-dolerite dykes occurring in the Shoalhaven Valley, which are of post-Devonian and probably pre-Kamílaroi age. All that can be said for the Tarago dykes is that they are post-Silurian.

Quartz-dolerite, Reedy Creek.—As with the dykes just mentioned, this is probably to be related to the Shoalhaven quartz-dolerites, which the writer intends to describe in a future paper. It occurs as a dyke twenty feet wide cutting the Mount Fairy Shales in Reedy Creek, K.4, about 30 chains below the main mass of limestone. A dyke of quartz-porphyry occurs two chains higher up, but there does not seem to be any connexion between them. The rock resembles in thin section the quartz-dolerite dykes of Crisps Creek.

Composite dyke, Sandhills Creek.—The types involved here are dolerite, aplite, and porphyritic dolerite, again showing features characteristic of the quartz-dolerite group. In north-western J.3, on Sandhills Creek, a dolerite dyke about 20 feet wide cuts the Mount Fairy Shales in an east-to-west direction. The dyke contains a sub-central band, two to three feet thick, of aplite. The relation of this to the parent dyke is not clear, but it appears that it split the latter after its intrusion, after the manner of composite intrusions. A few yards downstream large blocks of a porphyritic dolerite were found. Although not actually found *in situ* in the dyke, it is very probable that it is an associated type, and is here grouped with it.

Tachylytic basalt.—Specimen 1548 was collected in the railway cutting in south-eastern G.4. It shows the contact of aplite and tachylytic basalt. Thin sections show clearly that the aplite is intruded by the basalt. The rock is an intrusive basic type which, from its freshness, is probably no older than Devonian at most, since it shows no sign of the epi-Silurian diastrophism, and the felspars are quite fresh; possibly it is as recent as Pliocene. The rock may be related to a doleritic type (1552) from G-H.4. It is in the form of an inverted V, in the granite, the outcrop being an inverted V in the cutting wall, and two parallel bands in the floor. Possibly the shape is related to the joint system of the granite. This "dyke" trends at 40°. No slide is available.

Hornblende-epidote Rock.—This is an unsatisfactory type. In the southern part of I.4, in a tributary of Emu Flat Creek, basic rocks occur as bands a few feet thick, apparently interbedded with the Mount Fairy Shales. They are represented by specimens 1668 and 1669. Slides show that the rock consists of brown, with some bluish-green, hornblende in idiomorphic grains; associated with radiating epidote. This is a peculiar type, and no clues are known as to its origin.

Emu Flat Creek Dolerites.—A number of melanocratic rocks occur on Emu Flat Creek and nearby, in I.4. It is difficult to say definitely whether these are intrusions or xenoliths in the granite, since they are exposed only in the stream channel, and the critical junctions were largely covered. One of the masses contains coarse porphyritic phases, and is also intimately cut by an aphanitic type, which distinctly intrudes the granite as well, sending out tongues and seeking out the joint planes. On the other hand, at the old road crossing an exposure of basic rock more resembles a large xenolith. Moreover, this rock is distinctly more altered and different in thin section from the others. Very probably it is a xenolith while the others are dyke-rocks.

Physiography.

While the details of physiographic structure to be found in many regional settings are also to be found in the Lake George District, the discussion of the physiographic history of the area on modern lines can be satisfactorily dealt with only when treated as portion of a much larger unit. Broadly speaking, we may regard the Tarago to Bungendore area as an example of internal drainage—demanding some special explanation—superimposed on the conditions which must previously have obtained at the main divide between the coastal and western drainage systems. Discussion of this peculiar condition is left to a later paper, as it involves a much larger area than that dealt with in this paper.

Outcrop and Contour.—Much of the diversity of topographical detail is directly related to the geological structure. Prominent hills and ridges abound, and can in most instances be correlated with the nature of the rock. The steep hilly country to the south of the Tarago–Willeroo road occurs largely in slates, as do the surrounding flatter parts. However, the slates here have been considerably indurated by the granite close beneath. Intensely silicified bands are followed exactly by the minor ridges. The eminences of Sally Trigonometrical Station and Mount Ellenden (Governor's Hill) present slopes reaching 45°. (These slopes are quite stable in the present cycle of erosion, and most of them have a soil mantle.) The Sally group of hills consists of slates, but they have been indurated, and much impregnated by silica and iron. The ridges of Governor's Hill and Osborne Trigonometrical Station are composed of hard granite-gneiss. The marked elongation of these is probably due to the gneissic structure of the rock. The ridge of Osborne Trigonometrical Station is bounded on the east by low-lying slate country; on the west the change in topography is not so marked, as igneous rock, though of less massive type, continues. The hard flanks of Governor's Hill are bounded on the west by a soft amphibolite-slate complex, and on the east by jointed felsitic rocks. Possibly, also, the present surface represents fairly closely the original roof of the bathylith.

The Woolowolar Ridge, south of Tarago, is part of a long ridge running north to near Goulburn. Near Tarago at all events it shows all the signs of being due to differential erosion. It is built of resistant quartzites and felsites, and bounded on the east by weathered granite, and the west by soft shales. The rugged range running from Tarago to Spring Valley and along the north of Lake George, apparently owes its elevation to the same cause. As pointed out elsewhere, the chief rock type involved is a dense quartzite; where this gives way to granite or amphibolite, there is at once a change to lower ground.

Gullying.—A characteristic feature of the landscape is the extensive gullying which has gone on. An impressive picture of the apparently rapid erosion that has taken place is seen by standing in G.4 and looking westwards to Osborne Ridge, when a whole hillside seared with many gashes is viewed. The best example is perhaps in G.5, on Wright's Creek, which is here quite impassable, presenting vertical banks 20 feet high. Numerous observations, such as the occurrence of ox skulls in the alluvium banks, and the crossing of gullies by surveyed map roads, indicate that the gullying took place since white occupation, and during the last century. Deforestation at once comes under suspicion. However, such gullying was found to occur in places well away from any killed timber, gradually engulfing the vegetation. It may be that the rapid erosion at present occurring is not wholly to be attributed to deforestation, but is only affected in degree thereby. Whether the cause is a difference in annual rainfall, season of maximum precipitation, rate of precipitation, etc., is not clear. Bearing on this, Craft (1935) has just published the results of relevant observations on the Upper Murray Valley.

Aggradation of Low-lying Areas.—Many of the smaller streams in their lower courses pursue channels now very ill-defined, though the older parish maps show them clearly. Apparently this aggradation is of recent occurrence, and to be correlated with the extensive gullying noted above. Wright's Creek, D.4, shows both features very well. In many cases where the alluvium thus deposited has been later again cut into by the stream, regular alternations of coarse and fine beds occur.

Wind-blown Sand.—At various places along the eastern shore of the lake, considerable areas of a fine white quartz-sand with rounded grains occur. Notable among these are the large flats of the Currandooly and Willeroo Stations. These accumulations are especially found opposite breaks in the higher land on one or both sides of the Lake. The sand is economically valuable, supplying a constant flow in the streams, ample scope for wells, and much arable land. The sand is evidently wind-borne, and probably derived, in the last instance, from the lake bed.

Economic Geology.

Mention has been made above of the economic bearing of the deposits of limestone, dolomite, wind-blown sand, and alluvial flats of the district. Of importance also are the weathered granite or saprolite, much used as a road-surfacing material, and the soft shales, which have been used for brick-making.

Occasional pyritic replacements of the Mount Fairy Series have occurred near exposures of the granite. One such, a little south of the Tarago–Willeroo road, has been prospected by several deep shafts. At Currawang, there occurs a zone of mineralization of the amphibolite series, in which there has been considerable deposition of copper sulphides. The workings could not be examined, though there is evidence of a good deal of activity in the past, the ore being smelted locally. The surrounding areas of amphibolite show more pyrites as disseminated grains than is usual (see Carne, 1908, p. 341).

In portion 21, Parish of Mulwaree, and about one mile south-west of Tarago Trigonometrical Station, is a deposit of barytes, replacing limestone. This limestone is evidently a small outcrop to be grouped with the other Devonian limestones of the vicinity. Specimens of the limestone in all stages of replacement by the barytes may be obtained. The deposit does not appear to be very extensive. It is not possible to say whether the deposit is a groundwater replacement or is to be attributed to one of the nearby granites.

Geological History.

The earlier part of this history is rather vague. Probably earliest among those rocks of which we have knowledge were the gabbroic antecedents of the amphibolites, perhaps injected into a shale series now represented by the Red Hill phyllites; regional metamorphism converted these to amphibolites and hornblende-schists, and phyllitic types, respectively. Following extensive denudation, a shallow marine Upper Silurian (and possibly Lower Silurian) geosynclinal basin of considerable dimensions received muds and sands with considerable regularity

—a regularity displayed also by the occasional mild storms. At times, possibly far from land, coral reefs flourished, apparently at least twice. Occasional volcanic vents, on the shoreline or in the water, or both, emitted lavas which, in places, became interbedded with the sediments. Some of these, at least, seem to have been injected among the muds on the sea floor. Very regular emissions of ash took place at times. At the close of the Silurian, an orogeny ensued which compressed the rocks in the geosyncline into close folds; it was before this compressional movement had ceased that injection of granitic magma took place, insinuating itself among the bands of sediment, and also partaking of the impressed directional structures; movement had not ceased when the granite-gneiss had solidified.

Probably during the Lower Devonian, erosion was taking place on a considerable scale. The Middle Devonian saw shallow submergence of the land in another basin, and coral reefs again flourishing. Then followed, after an uncertain period, the ejection of coarse pyroclastic material, succeeded by some shale, flows of felsite, and finally a considerable thickness of sandstone. At some stage between the formation of the Middle Devonian reefs and the end of the deposition of the sandstone, there probably occurred a period of folding—the late Middle Devonian folding. Next occurred the intrusion of another granite, this time during tensional rather than compressional conditions, and at the close of another orogeny—the Kanimbla epoch—which folded the Devonian rocks and further dislocated the older ones, the sandstones were converted to quartzites. At some period later than this occurred the injection of most of the minor intrusives of the area—notably those of the quartz-dolerite kindred.

Erosion supervened, and has continued to the present day. In all probability the major stream-pattern of this part of the State was established as far back as the Triassic, but the internal drainage of the Lake George Basin is a later feature. Towards the end of the Tertiary, outpourings of basaltic lava covered a limited portion of the area. Probably at this stage the sand accumulations had begun to form, but these may be later than the Kosciusko Epoch, especially if this be related to the formation of Lake George. The Kosciusko Epoch did not leave any distinguishing marks on the area, except in so far as it may have affected the drainage of the region as a whole.

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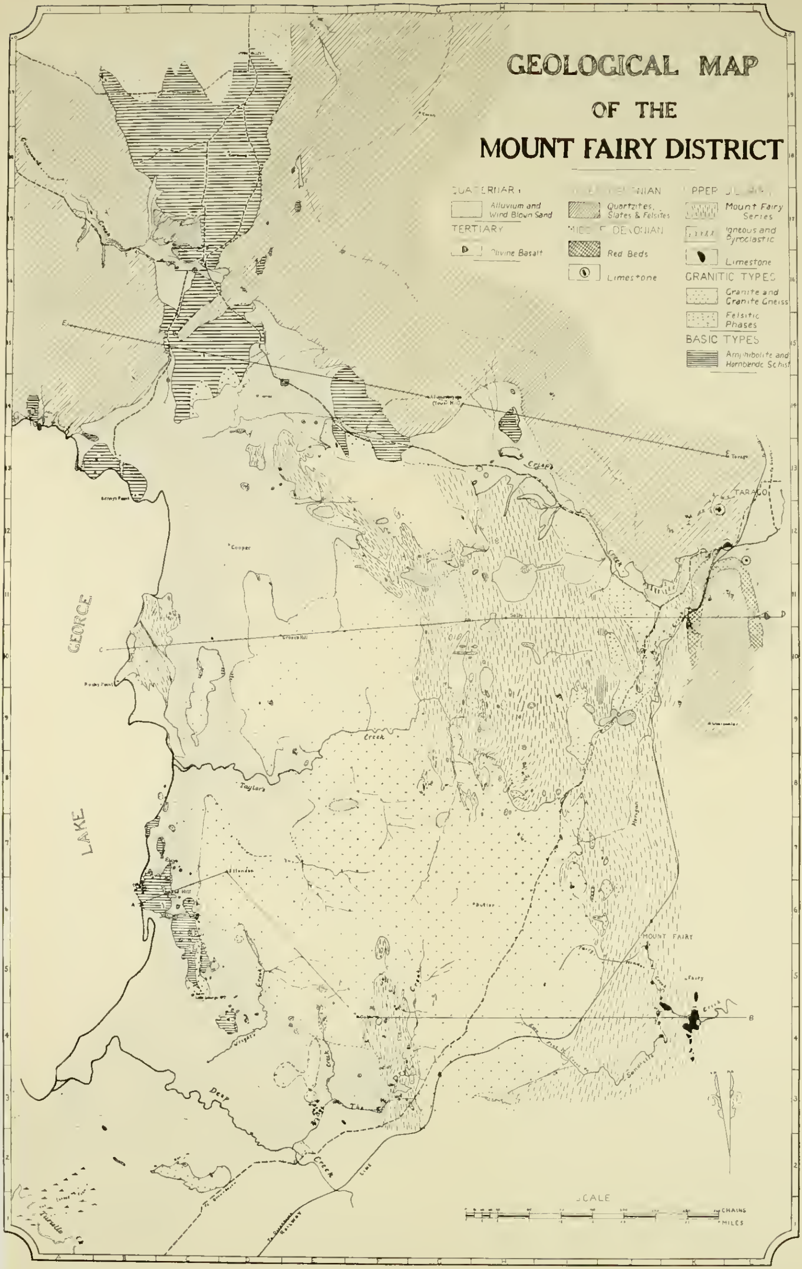
GEOLOGICAL MAP
OF THE
MOUNT FAIRY DISTRICT
Alluvium and Wind Blown Sand
TERTIARY
Olivine Basalt
Quartzites, Slates & Felsites
Red Beds
Limestone
Mount Fairy Series
Igneous and Pyroclastic
Limestone
GRANITIC TYPES
Granite and Granite Gneiss
Felsitic Phases
BASIC TYPES
Amphibolite and Hornblende Schist
LAKE
GEORGE
TARAGO
MOUNT FAIRY
Taylors
Creek
Deep
SCALE
CHAINS
MILES